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Modeling the effects of temperature on population parameters of *Chrotogonus homalodemus* (Blanchard, 1836) (Orthoptera: Pyrgomorphidae)

Nawal Zohdy M. Zohdy[1], Khaled M. Abdel Rahman[1], Nermeen R. Amer[1]☼, Wael M.ElSayed[1,2]

1. Department of Entomology, Faculty of Science, Cairo University, Giza, Egypt
2. Laboratory of Systematic Entomology, Division of Environmental Resources, Department of Agrobiology and Bioresources, Hokkaido University, Japan

☼Corresponding author : Laboratory of Ecology, Department of Entomology, Faculty of Science, Cairo University, Giza, Egypt, , e-mail: rnermeen@sci.cu.edu.eg

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ABSTRACT

Temperature is the most important key factor affecting insect's life. Eggs of *Chrotogonus homalodemus* (Blanchard, 1836) were considered as the sensitive stage to temperature. The 2nd and 4th instars were observed to possess the highest mortality rate. Adults had the longest life span up to 130 days and reached sexual maturity within 9-15 days. Fecundity of females reached 96.86 ± 2.72 eggs. The value of net reproductive rate was 9.71 ± 1.18. Development of the insect from egg to egg required 2464 day degrees. The grasshopper might have three generations per year.

Keywords: *Chrotogonus homalodemus*, Day Degree, developmental rate, global worming, population parameters

Abbreviations: gen. 1 and gen. 2 - generations reared under outdoor conditions, SR - Sex Ratio, n_m – number of males, n_f - numbers of females, R_o - Net reproductive rate, ♂ - male, ♀ - female, l_x - proportion of surviving nymphs to age x, m_x - mean number of eggs per female of age x, DD - Day Degree

1. INTRODUCTION

Temperature is the most important factor regulating life; therefore, it is important to study in detail more temperature effects on insect's life. Global warming is simply the rise of temperature of the Earth. This phenomenon is a problem forcing insects to produce more generations (Yamamura and Kiritani, 1998) or invading new places (Kuřavová, 2015).

In a previous work, Zohdy et al. (2015) have constructed a life table of *Chrotogonus homalodemus* (Blanchard, 1836). This non-diapause acridid species is a seedling pest and is widely distributed in Egypt the whole year round (Ibrahim 1971; Shahpa, 2004; El-Shazly and El-Sayed, 2005).

The present work aims to add more information on the response of the acridid, *C. homalodemus* (Blanchard, 1836), as a model affected by global warming in Egypt.

2. MATERIALS AND METHODS

Study sites and sampling method

Adults and nymphs of *Chrotogonus homalodemus* (Blanchard, 1836) were collected by bare hands from Abu-Qatada (30° 8' 33" N; 31° 23' 33" E), El-Mansouria (30° 25' 5" N; 31° 10' 56" E) and Abu-Raŭwash (30° 9' 25" N; 31° 18' 9" E) districts, Giza Governorate, Egypt. The collected acririds were reared in the laboratory in the Department of Entomology, Faculty of Science, Cairo University under controlled laboratory conditions. The rearing cages (50 X 50 X 70 cm) were kept under a photoperiod of 12:12 (D:L) using 150W lamp that was controlled by a thermostat (32±1°C) as suggested by Shahpa (2004). Two sides of the cages were made of wire mesh screens and the other sides were made of wood. Cages were provided with suitable ovipositional containers (10 cm deep) filled with sieved, washed and sterilized sand that was regularly kept moist. Hatched individuals of *C. Homalodemus* (Blanchard, 1836) were maintained on clover, *Trifolium alexandrinum* (L), from November to June and then on garden purslane, *Portulaca oleracea* (L) from July till October (Ibrahim, 1971).

Rearing protocol and the effect of temperature

To estimate the effect of temperature; 150 freshly deposited eggs (three replicates each of 50 eggs), were collected from different egg pods and were incubated at constant temperatures of 25, 30, 32, 35, 40 and 42°C till hatching. The mean incubation period and percentage hatchability of the eggs were recorded. The percentage rate of egg development at each level of temperature was calculated according to the following equation:

(1/ incubation period) X 100

Threshold temperature was determined by plotting the rate of development against the respective temperature. The intersection of the straight part with the X-axis shows the hypothetical threshold temperature (Reference).

The newly hatched nymphs were subsequently reared under the same temperature levels (25, 30, 32, 35, 40 and 42ºC) and a photoperiod of 12:12 (D:L) till adult emergence and deposition of the first egg pod (female maturation). The mean duration of each instar as well as the mean time elapsed between adult emergence and maturation was recorded. The developmental rate of both nymphs and adults was calculated using equation-1. Threshold temperatures for each of the nymphs and mature adults of *C. homalodemus* (Blanchard, 1836) were estimated as previously mentioned.

In order to compute the effect of controlled temperature (32±1°C) on the mortality rate of immature stages, eggs and nymphs, of *C. homalodemus* (Blanchard, 1836); freshly deposited eggs (three replicates each of 300 eggs) were collected randomly from different egg pods from the stock culture and were incubated in an electrically operated digital incubator (Haier® incubator) maintained at 32±1ºC till hatching. The number and percentage of egg mortality were recorded and tabulated.

The newly hatched nymphs were kept under the same conditions as eggs. Further observations on different instars were continued till adult emergence. The number of dead individuals was recorded and the percentage mortality rate of nymphs was also calculated.

It has to be mentioned that, since all the nymphs in the cages were in the same age, it was expected that moulting should occur on the same day, but in practice, it was found that there was 1-3 days of deviation in moulting from the 1st instar to the 2nd one and from 2nd instar to the 3rd one and so on up to the 6th instar. In order to minimize this bias; newly emerged 2nd instars (0 day old) were collected and transferred in a separate rearing cage and the same procedures were carried out for the subsequent instars.

To estimate the mortality rate of immature stages of *C. homalodemus* (Blanchard, 1836) reared under outdoor conditions for two successive generations: (gen. 1 and gen. 2); the previous methods were applied. It is important to be mentioned that only the daily average temperature was used as a factor in this experiment.

Population parameters

To determine certain specific population parameters concerning *C. homalodemus* (Blanchard, 1836) reared under both controlled and outdoor conditions, the following equations were used:

1- Mean sex ratio (SR): was calculated according to Carey (1993) as follows:
SR= number of males (n_m): numbers of females (n_f), for each generation.

2- Adult maturity**:** the period from adult emergence till they lay the first egg pod was taken as an indicator for adult maturation (Jone, 1970).
To estimate the period of adult maturity of adults reared under outdoor or controlled conditions (32±1°C); seven sets each of one pair of male (♂) and female (♀) were taken from newly emerged adults and continued to be reared till laying the first egg pod.

3- Number of egg pods per female: seven sets each of one pair of male (♂) and female (♀) was taken from newly emerged adults; they were continued to be reared under constant temperature and outdoor conditions till death of adults. The mean number of laid egg pods was calculated following Mariottini et al. (2010).

4- Number of eggs per pod: To count the number of eggs per pod; 10 egg pods from different females were kept in moist filter paper on Petri dishes (Ø=10 cm). The frothy material was removed from the egg pods by nylon haired brush (no.2) and fine forceps and hence the eggs were easily exposed and separated and their number per pod was counted (Mariottini *et al.,* 2010).

5- Fecundity: Fecundity was calculated by multiplying the mean number of egg pods laid per female by the mean number of eggs per pod (Das et al., 2012).

6- Net reproductive rate (R_o): it is expressed as the mean number of female offspring produced per female per generation. This was calculated according to Mariottini et al. (2010) as follows:

$$\sum_{x=1}^{n} l_x m_x$$

where l_x is the proportion of surviving to age x.
m_x is the mean number of eggs per female of age x.

For degree day modal application, the previously gathered data of threshold temperature and duration of different stages reared under controlled and outdoor conditions (gen. 1 and gen. 2) were used to calculate the day degree (DD) using the formula:
DD = (Maximum temperature + Minimum temperature / 2) – Threshold temperature.

Statistical analysis

Calculations for degree-day accumulations were computed using DEGDAY® ver. 1.01 software (Higley *et al*. 1986), which is a functional program running on Win® 7 personal computer and derives degree-day accumulations by rectangle, sine-wave, and triangle methods. In this experiment, we used single triangle method as suggested by Murray (2008).

For temperature controlled generation (32±1ºC), day degrees (DD) of eggs, nymphs and mature adults can be calculated using the above mentioned formula. Also, we can calculate the accumulated day degrees of each stage by adding the day degrees along the duration of each stage. Moreover, by adding the accumulated day degrees of eggs, nymphs and mature adults we could estimate the accumulated day degrees (Thermal constant) of the entire generation.

For outdoor generations (gen. 1 and gen. 2), average daily temperature were recorded in order to calculate day degrees and then accumulated day degrees of each stage and the entire generation using DEGDAY® software. By relating thermal constant of the entire generation to the accumulated day degrees along the year, we could predict the number of generations in a given year.
For statistical analysis, the software PAST® was used for analysis and the probability was set at $P \leq 0.05$.

3. RESULTS

Effect of temperature on mortality rates of eggs:

It was evident that eggs of *C. homalodemus* (Blanchard, 1836) reared under both controlled and outdoor conditions were considered as the sensitive stage to temperature (table 1). Eggs had the highest mortality rate as compared to the different instars (28.66%, 24.66% and 37.66% for controlled and outdoor conditions [gen. 1 and gen. 2]; respectively). The mortality rate of egg stage of gen. 2 (average temperature was 39.7°C) was higher than that observed for gen. 1 and that recorded for the controlled generation at constant temperature (32±1ºC).

Effect of temperature on mortality rates of nymphs:

For both controlled and outdoor reared generations, nymphs passed through six successive instars. However, some females (20% of the total emerged females) underwent an extra molt. The total duration of the nymphs, whether with or without the extra molt, was covered in about the same time. Mortality rate of 2nd and 4th instars for controlled condition were 7.38 and 9.49%, respectively; those reared under outdoor condition (gen. 1) were 10.57 and 15.11%, respectively. Whereas the mortality rate of the 1st, 2nd and 4th instars of gen. 2 were 17.11, 19.35 and 11.96%, respectively. Also, they had the highest mortality rate compared to rest instars (table 1). These results revealed that the 2nd and 4th instars were common between all instars in the higher mortality rate.

Table 1

Average mortality rate of the immature stages of *Chrotogonus homalodemus* (Blanchard, 1836) reared under 32±1°C (control) and outdoor conditions (gen.1 and gen.2).

Stage \ Rearing condition		Control	Outdoor conditions	
			gen.1	gen.2
Egg		28.66	24.66	37.66
Nymphal instar	1st	5.14	7.96	17.11
	2nd	7.38	10.57	19.35
	3rd	4.78	7.52	6.40
	4th	9.49	15.11	11.96

	5th	1.85	2.73	1.94
	6th	0.00	0.00	0.00

Effect of temperature on incubation periods of eggs:

Concerning the incubation period, it was observed to vary according to the prevailing conditions of rearing. The incubation period elapsed for 20 days for eggs reared under controlled constant temperature (32±1°C). A significance difference (P ≤ 0.05) could be observed when comparing the incubation period of eggs reared under controlled condition to those reared under outdoor conditions (gen. 1 and gen. 2) (25 and 18 days, respectively). However, eggs of gen. 1 recorded the longest period (25 ± 0.23 days) where the average temperature was 18°C (table 2).

Table 2

Average duration (days: X±SD) of different stages of *Chrotogonus homalodemus* (Blanchard, 1836) reared under 32±1°C (control) and outdoor conditions (gen. 1 and gen. 2).

Rearing conditions / Stage	Control	Outdoor conditions	
		gen.1	gen.2
Egg	20.30 ± 0.038 [a]	25 ± 0.23[b]	18 ± 0.2[c]
Nymph	87.03 ± 0.022[a]	85 ± 0.173[b]	69 ± 0.251[c]
Adult (♂:♀)	130 : 110	120 : 110	90 : 80 [a]

Numbers followed by different letter in the same row are significantly different (P ≤ 0.05)

Effect of temperature on nymphal life span:

Nymphal periods differed in both controlled and outdoor generations (P ≤ 0.05). They were 87, 85 and 69 days for controlled conditions and outdoor conditions gen. 1 and gen. 2; respectively. Moreover, the nymphal period of the controlled generation was the longest (table 2).

Effect of temperature on adult longevity:

Adult span was considered as the longest stage. Females lasted about 110 days while males lasted about 130 days till all adults die (table 2). For gen. 1; females lasted about 110 days while males lasted about 120 days (average temperature was 32°C) and that of gen 2 was 80 days for females and 90 days for males (average temperature was 19°C) as shown in table (2).

Effect of temperature on the chosen population parameters:

Population parameters are summarized in table (3). The mean sex ratio (♂:♀) of adults emerged in the control, gen. 1 and gen. 2 insects were 0.541:0.459, 0.471:0.528 and 0.584:0.415; respectively. The sexual maturity was reached in 9-15, 8-15 and 11-17 days for control, gen. 1 and gen. 2; respectively. The mean number of egg pods/female was 3.40±0.64, 3.28±0.42 and 2.43±0.57 for control, gen. 1 and gen. 2; respectively.

The mean number of eggs per pod was 28.49±2.98, 29±2.87 and 19.57±2.59 eggs for control, gen. 1 and gen. 2; respectively. The 2nd outdoor generation produced less eggs/pod than the control and 1st outdoor generation (P ≤ 0.5).

Mean fecundity was 96.86±2.72, 95.12±2.42 and 47.55±1.56 eggs for control, gen. 1 and gen. 2. It is clear that later produced fewer eggs than the others (P ≤ 0.05) (table 3).

The value of net reproductive rate (R_o) for gen. 1 was 11.71±1.23. This value was 4.85±0.670 for gen. 2. This difference was significant (P ≤ 0.05). R_o value for both gen. 1 and gen. 2 were significantly different (P ≤ 0.05) from that of the control (9.71±1.18) (table 3).

Table 3

Population parameters of *Chrotogonus homalodemus* (Blanchard, 1836) reared at 32±1°C (control) and outdoor conditions (gen.1 and gen.2).

Population parameters		Control	Outdoor conditions	
			gen. 1	gen. 2
Mean Sex ratio (♂:♀)		0.541 : 0.459	0.471 : 0.528	0.584 : 0.415
Sexual maturity (days)		9~15	8~15	11~17
No. of egg pods per female	Mean ± SE	3.4 ± 0.64	3.28 ± 0.42	2.43 ± 0.571
No. of eggs per pod	Mean ± SE	28.49 ± 2.98	29 ± 2.87	19.57 ± 2.59*
Fecundity	Mean ± SE	96.86± 2.72	95.12 ± 2.42	47.55 ± 1.56*
Net reproductive rate (R_o)	Mean ± SE	9.71 ± 1.18	11.71 ± 1.23	4.85 ± 0.670*

* Significant (P ≤ 0.05)

Degree Days represented the daily accumulation of temperature above threshold temperature. Summation of these degree days along each stage period (Degree days x Stage period) is termed growing degree days or thermal constant *i.e*; it is the total accumulated temperature above threshold temperature needed to complete specific stage.

In this experiment, we applied degree day model on control, gen. 1 and gen. 2 in order to estimate the thermal constant of *C. homalodemus* (Blanchard, 1836) generation. Table (4) summarizes: threshold temperature for each stage, degree days and growing degree days for each stage and for the total generation of *C. homalodemus* (Blanchard, 1836) reared as control or gen. 1 and gen. 2.

Eggs of *C. homalodemus* (Blanchard, 1836) required about 345 DD_s to hatch under controlled under 32±1°C.; while gen. 1 and gen. 2 required 269 and 299 DD_s; respectively. Nymphs required about 1849 DD_s to be adult under 32±1°C, while gen. 1 and gen. 2 required 1615 and 1504 DD_s, respectively. Adults required about 270 DD_s to reach maturation and lay their first egg pod in control insects, while gen. 1 and gen. 2 required 286 and 255 DD_s, respectively (Table 4).

Table 4

Thermal units accumulation (DD's) for eggs, nymphs and mature adult of *Chrotogonus homalodemus* (Blanchard, 1836) reared at 32±1°C (control) and outdoor conditions (gen.1 and gen.2).

			Threshold temperature (˚C)	Duration (in days) (mean ± SE)	Day degree above threshold temperature (DD_s)	Growing day degrees of each stage (GDD_s)	Accumulated growing day degrees (GDD_s)	
							Egg to Adult	Egg to Egg
Control		Egg	15	20.30 ± 0.038	17	345	2194	2464
		Nymph	8	77.03 ± 0.022	24	1849		
		Mature adult	5	10.01 ± 0.012	27	270		
Outdoor conditions	**gen. 1**	Egg		25 ± 0.230	10.76	269	1884	2170
		Nymph		85 ± 0.173	19	1615		
		Mature adult		11 ± 0.351	26	286		

gen. 2	Egg		18 ± 0.200	16.61	299	1768	2023
	Nymph		69 ± 0.251	21.80	1504		
	Mature adult		15 ± 0.360	17	255		

Table 5

Accumulated degree days during three consecutive years 2012, 2013 and 2014.

Ordinal date	Year		
	2012	**2013**	**2014**
0	0	0	0
30	403.28	442.7	464.6
60	827.655	892.8	923.7
90	1358.51	1507.4	1512.3
120	2040.03	2158.7	2196.5
150	2859.05	2997.8	3005.7
180	3740.06	3848.8	3859.4
210	4685.64	4729.2	4762.4
240	5628.99	5652.1	5690.3
270	6460.84	6483.6	6544
300	7259.9	7206.3	7290.8
330	7860.58	7831.1	7878.7
360	8185.61	8276.7	8389

The growing degree days from egg to adult emergence for control insects, gen. 1 and gen. 2 were 2194, 1884 and 1768 GDD_s; respectively. These differences were significant ($P \leq 0.05$). The same result was obtained for the growing degree days from egg to egg.

Accumulated day degrees along three consecutive years (2012~2014) (table 5) indicated two important points: the first was that accumulated day degrees during 2013 was 8277 DD_s, by dividing this year accumulation on the thermal constant of *C. homalodemus* (Blanchard, 1836), we could predict the number of generations during 2013. It was estimated to be about 3 generations/year and this prediction could prove the outdoor observations. The second point was that the accumulated degree days increased from 2012 to 2013 and reached the highest value during 2014 (8186, 8277 and 8389 DD_s, respectively). This could indicate that there was a yearly increase in the average temperature and also the accumulated degree days increased yearly in which the accumulated day degrees of year 2013 increased by about 1.09% compared to that of 2012 while the accumulated degree days of 2014 increased by about 1.33% than that of 2013. This increase in average temperature and then on yearly accumulated degree days would offer two points: the first point was that the increase in yearly degree days accumulation might resulted in increase in the number of generations on the long term. The second point could point out on the global warming phenomena.

4. DISCUSSION

Estimation of certain population parameters under both controlled and outdoor conditions (1st and 2nd generations) could reveal the possible role of temperature in the acceleration or retardation of the development of the experimental acridid. Adults reared under controlled temperature and those of 1st outdoor generation nearly followed the same duration to reach sexual maturity while those of 2nd outdoor generation took relatively longer period which may be due to difference in the average temperature under which they were reared as the 2nd outdoor generation reached adult stage in October where the average temperature was lower than that

of 1st outdoor temperature that reached adult stage in May, so adults of 2nd outdoor generation took longer period to take degree days needed to reach maturation. Willott and Hassall (1998) indicated that the maturation time of *Chorthippus brunneus* (Thunberg, 1815), *Omocestus viridulus* (Linnaeus, 1758), *Myrmeleotettix maculates* (Thunberg, 1815) and *Stenobothrus lineatus* (Panzer, 1796) increased with decreased temperature from 35 to 30ºC. Females of the 2nd outdoor generation revealed significant decrease in the number of produced egg pods, number of eggs per pod, fecundity and fertility compared to those of controlled and 1st outdoor generations which might be a result of relatively low average temperature. Willott and Hassall (1998) also found that females of *C. brunneus* (Thunberg, 1815) produced more eggs at higher temperature and the total number of laid pods during the life time of a female was greatly reduced by the decrease in temperature as a result of the physiological changes during developmental time. Cyr et al. (1991) estimated the annual egg production of *Hadenoecus subterraneus* (Scudder, 1863) during winter and found that, 20–30 eggs were laid by individually caged female crickets in a 2–3 day period of rapid egg laying, while in early summer, the rate was 1–3 eggs laid every eight days and then the annual egg production was 96 to 371 eggs laid per year per female.

Degree day (DD) models were important tools for predicting insect life stages based on their developmental rates at certain temperatures. It could be useful to help time scouting activity and to avoid missing injurious pest populations which may improve pest management decisions. Hewitt (1980) and Kemp et al. (1991) found that plant phenology was useful in determining development and timing that might help in grasshopper control applications. Also, they suggested that degree-day accumulation may provide a good estimation for adult occurrence. Growing degree days (GDD_s) used to define the average number of temperature degrees above threshold temperature over a given 24 hour period. Thus, the number of GDDs recorded during a day was an estimate of the energy that was available to a given organism for growth and development. In the present study, it was clear that the growing degree days required for the development of each stage or for the entire generation of *C. homalodemus* (Blanchard, 1836) reared under constant temperature (32±1ºC) differed than those reared under outdoor temperature. Developmental rate of immature stages of *C. homalodemus* (Blanchard, 1836) was assumed to be affected by variations in local soil temperature (Pierson and Wright, 1991), as well as behavioral responses to temperature (O'Neill and Rolston 2007) and to solar radiation (Bryant et al., 1998). Berry et al. (1999) stated that degree day accumulation affecting rates of development vary widely by species and vary from one year to another (Brust et al., 2009). Siddiqui and Barlow (1973) found that there was no clear consensus on the point that the developmental rates measured at constant temperature may be higher or lower than that measured at fluctuating temperature. On the other hand, Tu et al. (2014) found that the empirical degree day values were not absolutely constant even if the feeding and all other environmental influences were the same. Willott and Hassall (1998), on their study of the response of British grasshopper to temperature change, found that females of *C. brunneus* (Thunberg, 1815) and *S. lineatus* (Panzer, 1796) required about 370 DD above the threshold temperature to reach adults' eclosion while *O. viridulus* (Linnaeus, 1758) and *M. maculatus* (Thunberg, 1815) females required 320 and 250DD; respectively. Brust et al. (2009) during their studies in Nebraska (USA) found that the adults' appearance of common species of grasshoppers varied widely between the years 2005 and 2007 as a result of yearly climatic differences.

Using degree day model, we could possibly predict the number of generation per years which varied according to climatic change. Tu et al. (2014) in his study on *Locusta migratoria* (Linnaeus, 1758), suggested that, in laboratory experiment, the number of available heat units (DD) influenced the number of produced locust generations. While Harrington and Stork (1995) concluded that there is currently much interest in the consequence of climate change on insect populations. Jones (1997) cited that biotic factors modified the number of generations in any one location, and might be influenced by the number of host species in an area. Also, Jones (1997) found that predictions using the degree day approximation were more accurate than those from life table studies using calendar time.

Brust et al. (2009) suggested that treatment of economic numbers at earlier instars, such as 2nd and 3rd instars, should prevent more damage as timing of sampling and treatment based on degree-day estimation. Global warming and climatic change referred to the rise in the average temperature of the earth's climate system and its related effects (Hartmann et al., 2013). The observed increase in global average surface temperature and atmospheric carbon dioxide had been much faster in recent decades. Droughts, heavy rainfall and heavy snowfall might be resulted due to extreme weather (Battisti et al., 2009). US Environmental protection agency in 2009 indicated that the measurements of the sun's output had not increased since 1978, so the warming during the past 30 years cannot be attributed to an increase in solar energy reaching the earth. This changes in temperature might be due to increase in the amount of greenhouse gases since the industrial revolution which resulted in increasing the concentration of carbon dioxide and methane to levels that were much higher than any time during the last 800.000 years (Rowan et al., 2007).

5. CONCLUSION

It has to be mentioned that the observed increase in the recent global average surface temperature and atmospheric carbon dioxide have been much faster in recent decades that resulted in change in daily and then yearly growing day degrees (GDD_S). In the present research, the recorded accumulative degree days along the three consecutive years (2012, 2013 and 2014) showed an elevation on yearly accumulation of degree days. Furthermore, the increase in the rate of elevation from 2013 to 2014 was comparatively higher than that recorded from 2012 to 2013 which might reveal the global warming phenomena.

FUTURE ISSUES

Overall, it is expected that most ecosystems will be affected by higher atmospheric carbon dioxide with higher global warming that might result in the extinction of many species and reduce the biodiversity. In this since, the authors believe that more researches and studies should be conducted on different taxal levels together with other environmental factors in an attempt to construct a corner stone in biodiversity and conservation ecology.

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